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Visual assessment of the timing of bruising by forensic experts

M.L. Pilling BMedSci (Hons) (Medical Student)^a, P. Vanezis OBE PhD FRCPATH (Professor)^{b,*},
D. Perrett PhD CChem FRSC (Professor)^c, A. Johnston PhD FRCPATH (Professor)^d

^a Barts and The London School of Medicine and Dentistry, University of London, UK^b Cameron Forensic Medical Sciences, Barts and The London School of Medicine and Dentistry, University of London, UK^c Bioanalytical Science, Barts and the London School of Medicine and Dentistry, University of London, UK^d Clinical Pharmacology, Barts and The London School of Medicine and Dentistry, University of London, UK

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ABSTRACT

Introduction: Forensic experts are frequently asked to comment on the age of injuries and interpretation may have significant medico-legal consequences. The purpose of this study is to determine the accuracy with which forensic experts can visually age a bruise from photographs produced under standard conditions.

Methods: Bruises were produced on the upper arms of 11 subjects by a suction pump. Sequential photographs were taken daily until they were no longer visible to the naked eye. Fifteen forensic experts who did not know the age of the bruises were asked to estimate their ages and also to place them in chronological order.

Results: Hundred and thirty-two images of 25 bruises were produced, ranging from 0 to 209 h in age. There was considerable inter- and intra-observer variability in accuracy (median difference between the estimated age and the real age = 26.0 h (95% C.I. 24.0–31.0 h). There was greatest accuracy for bruises photographed between 0 and 12 h. No significant differences were seen between male and female observers ($p = 0.553$) and performance was also unaffected by the age of the observer ($p = 0.160$). Of the bruise images placed in chronological order >80% of the observers made between 0 and 2 errors.

Conclusion: Bruise age estimates by forensic experts, from photographs, are unreliable. However, it appears that the vast majority of observers are better able to place bruises from the same subjects in their chronological order.

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1. Introduction

The evaluation of any tissue injury, is an essential component of forensic practice.^{1,2}

Forensic experts are frequently asked to comment on the age of bruises, in cases such as child abuse, assault and sexual assault. Their interpretation may have significant medico-legal consequences,³ including the incrimination or exclusion of a suspect as the perpetrator of a crime.

A bruise is a focal discoloration of the skin,⁴ caused by an extra-vascular collection of blood under an intact epidermis, following trauma to the body by the impact of a blunt instrument.^{1,5} For a bruise to occur two things must happen:

- (i) The skin and/or underlying tissues must be sufficiently crushed or stretched by a mechanical force for the small vessels within to be ruptured, without breaching the surface of the skin.^{6,7} For this to occur, the trauma must be caused by a blunt instrument, otherwise the skin surface will be cut, and the force must not be so great that the elastic limit of the skin is exceeded and the skin is 'split', forming a laceration.⁷
- (ii) Blood must leak from the damaged vessels into the surrounding tissues.⁶ This requires sufficient pressure within the blood vessels to expel the blood,⁸ and thus a bruise, in almost all cases, is an ante-mortem event.⁹

Once blood is within the tissues, the body launches an inflammatory response to degrade and remove it.^{6,10} Macrophages phagocytose the red cells and the haemoglobin is degraded. Haemoglobin is one of the dominant absorbing chromophores, determining the colour of skin,^{11,12} and its appearance varies (red/blue/purple) depending on its oxidative state and depth within the skin.^{12–14} It is the biochemical breakdown of the Haemoglobin in red cells that accounts for the colour changes that may be observed within a bruise.⁶ Haemoglobin degradation is catalysed

* Corresponding author. Address: Cameron Forensic Medical Sciences, Clinical Pharmacology, Barts and The London, London EC1M 6BQ, UK. Tel.: +44(0)20 7882 3401, mobile: +44(0)7802 563 223; fax: +44(0)20 7882 3408.

E-mail address: p.vanezis@qmul.ac.uk (P. Vanezis).

by Haem-oxygenase producing Biliverdin (green), Carbon Monoxide and an Iron atom.^{6,10} The Iron atom released forms a complex with the protein Ferritin to produce Haemosiderin (brown).¹⁰ Biliverdin is then rapidly metabolised to Bilirubin (yellow).¹⁰

Currently, the ageing of a bruise is made primarily by observing the colours within it, and using the experience and expertise of the observer. Photographs are taken at the time of examination, in order to illustrate the findings and because it may not be possible to re-examine at a later date. However, previous research has identified many potential problems with this method, leading to significant doubts in the accuracy with which forensic experts are able to date bruises.^{15–18}

2. Variability in bruise appearance

The development and resolution of a bruise, in terms of its appearance, is extremely variable, both between individuals and within the same person. In general, the greater the damage to the blood vessels, the bigger the bruise, however, the size and intensity of the bruise does not necessarily indicate the strength of the force applied.⁶ The appearance of a bruise will depend on:

- Factors relating to the victim e.g. age, sex, % body fat, bleeding diatheses and skin colour.
- Factors relating to the infliction of the bruise e.g. force applied, site of infliction and type of weapon.

2.1. Subjectivity of colour perception

Rather than being an intrinsic property of an object, colour is the sensory perception of the interaction between that object and the constituent wavelengths of the incident light.¹⁹ Colour perception is, by nature, very subjective and will vary with: the 'nature and quality' of the incident light, the nature of the interaction between light and matter; the background and also the observer's interpretation of the light waves detected by their visual system.¹⁹ A study conducted by Munang et al., in 2002, found that there was significant inter-observer variability in colour descriptions of bruises.¹⁵

2.2. All colours except yellow appear to be unrelated to age

Two photographic studies have found that the only colour which has any bearing on the age of a bruise is yellow.^{17,18} Other colours may be apparent at any time. Langlois and Gresham conducted a study using 369 photographs of bruises of known age on 89 subjects aged 10–100 years. The photographs were visually assessed for the presence of particular colours. The study concluded that a bruise containing the colour yellow must be older than 18 h (although its absence did not suggest that the bruise was younger than 18 h).¹⁷ The second study, which looked at images of 50 accidental bruises in children, did not find a yellow hue in any bruise under 24 h old.¹⁸

2.3. Variability in the threshold at which individuals can perceive yellow

A later study by Hughes et al., digitally modified images of bruises to contain increasing amounts of yellow, from 2% to 20%. The point at which each observer could perceive yellow was recorded. The study identified variability between individuals in the threshold for the perception of the colour yellow and also showed that the 'ability to perceive yellow declines with age'.¹⁶

2.4. Unreliable photographic colour reproduction

If bruise age estimates are to be made from photographic images, then the colours within the photographs must represent the colour within the bruise. However, photographic colour reproduction is notoriously unreliable and depends on factors such as: the camera, the ambient lighting and the printer. The study conducted by Munang et al. also identified intra-observer variability between colour descriptions of bruises in vivo and those made from a photograph.¹⁵

The photographic study by Stephenson and Bialas used 1 experienced 'blind' observer to estimate whether the bruises in the pictures were fresh (<48 h), intermediate (48 h to 7 days) or old (≥ 7 days). The estimates were found to be 'unreliable'.¹⁸ A more recent study assessed the accuracy of physicians examining bruises in vivo, where features other than colour could contribute to their interpretation. It showed that emergency paediatricians, experienced in examining injuries in children, were able to age bruises to within 24 h of the actual age less than 50% of the time.²⁰

The purpose of this study was to determine the accuracy with which forensic experts can visually age a bruise from photographs produced under standard conditions.

3. Methodology

Healthy adult Caucasian subjects were recruited from the investigators and senior members of academic staff. Participants inflicted bruises on themselves by applying suction to the surface of the skin. This was achieved using a mains operated suction pump connected to the barrel of a 30 ml syringe by tubing (Fig. 1). The plunger of the syringe was removed and the open end of the barrel was applied to the anterior aspect of the upper arm for a total of 15 min. This produced uniform circular bruises ~3 cm in diameter.

Upon removal of the suction pump, photographs were taken immediately (Time 0), under standard ambient lighting conditions using a digital single-lens reflex camera (Canon EOS 350D) with an EFS 18–55 mm lens and a macro ring-flash (Canon MR-14EX) (Fig. 2). All images included a colour scale, to minimise colour distortion, and a centimetre scale. All images were taken of the bruise site only and were, therefore, non-identifiable.

When possible, sequential photographs were taken daily until the bruise was no longer visible to the naked eye. The camera settings were kept constant and the images were taken under standard ambient lighting conditions.



Fig. 1. Bruise production.

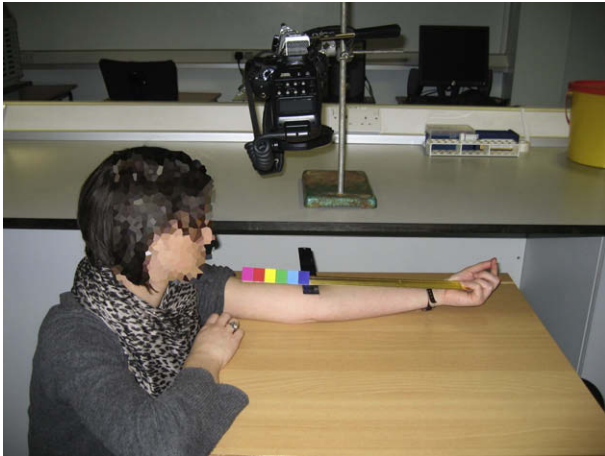


Fig. 2. Bruising participant being imaged with colour scale.

The images were uploaded onto a computer in RAW format. They were then edited in Adobe Photoshop Elements 5.0 to be of the same orientation and to remove any non-bruise age-related features, such as the imprint of the syringe, which would indicate to the observer that it was a fresh bruise without requiring them to look at the properties of the bruise itself. Fig. 3 illustrates the images that were produced following editing.

The images were saved in TIFF format to prevent loss of data by compression of the file and were then printed by a professional photographic printing company.

Forensic medical examiners attending the Diploma of Forensic Medical Sciences course at Barts and The London, School of Medicine and Dentistry were recruited.

Task 1 – Each participant was shown one image of each bruise produced. The particular image of each bruise that they were shown was selected at random using a random number generator.

The participants were then asked to:

- (i) Estimate the age of each bruise (in hours).
- (ii) To give an age range, in which they thought that the true age of the bruise lay; the size of which would indicate their confidence in their original estimate.

Task 2 – The participants were then shown a series of images of the same bruise at different ages. There was variation in the start and finish time between different series. The images were presented to them in a random order allocated by a random number generator. They were then asked to rearrange them in order of age (youngest – oldest).

3.1. Statistical analysis

The data was collated and analysed using the statistical package Minitab® 15.1.1.0.

4. Results

One hundred and thirty-two images of 25 bruises on 11 different subjects were produced. Bruise ages ranged from 0 to 209 h (45.5% \leq 24 h old). Sixteen observers, unaware of the true bruise ages, viewed the images.

4.1. Task 1

Overall, the median difference between the estimated age and the true bruise age was 26.0 h (95% C.I. 24.0–31.0 h) (see Table 1). However, there were a large number of extreme misjudgements



Fig. 3. Example of the images printed, showing the bruise, colour- and centimetre-scale.

made by many of the observers. The most extreme misjudgement was 454 h out (nearly 19 days). This is illustrated in Fig. 4 which shows the range of accuracy for each observer. There was considerable variability in accuracy between observers (IQR = 9.8–72.0 h).

In general, the more accurate the observer the less variable they were in their accuracy ($r^2 = 0.7$, $p < 0.05$).

There was a direct association between the true bruise age and the median absolute difference ($r^2 = 0.8$, $p < 0.05$), meaning that as the true bruise age increased the accuracy decreased. Therefore, the bruise ages were divided into nine categories. (The three categories used by previous studies were found to be too broad for our data.)^{18,20} The real bruise age was then compared to the age estimated by the experts to determine the accuracy for each bruise age range (Table 2).

As expected, the greatest accuracy was achieved in the youngest bruise category (0–12 h), with 52.1% (95% C.I. 43.6–60.6%) being

Table 1

Median, 95% confidence interval, inter-quartile range, mean, minimum and maximum values for the overall absolute differences between the estimated age and the real age.

Median absolute difference	26.0 h
95% C.I.	24.0–31.0 h
IQR	9.8–72.0 h
Mean absolute difference	52.9 h
Min absolute difference	0 h
Max absolute difference	454 h

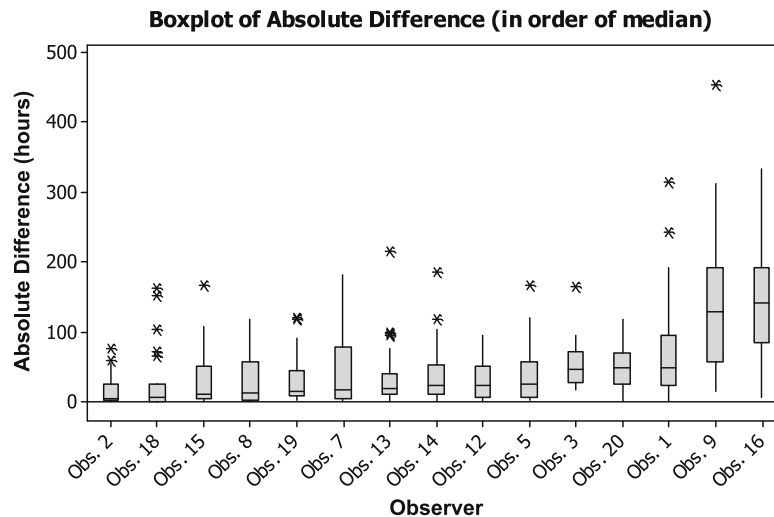


Fig. 4. Boxplots showing the absolute differences between the true bruise age and the estimated bruise age for each observer (in order of the median difference).

correctly allocated (Fig. 5). As the bruises increased in age, the observers were increasingly less able to allocate the images to the correct age group, with the exception of the final two categories (145–168 and >168 h) in which 18.2% of the images were correctly allocated, whilst none of the images in the two categories prior to that were correctly allocated. However, in the older age categories, there were relatively few images observed in those categories and since the confidence intervals overlap it is possible that this is due to chance. As the true age of the bruises increased the confidence intervals increased in size, reflecting the fact that the number of bruise images available for viewing decreased with age.

For all age categories, accuracy was 29.1% (95% C.I. 24.5–33.9%).

There was no relationship between accuracy and the age of the observer ($r^2 = 0.1$, $p = 0.2$) (Fig. 6).

There was also no statistically significant difference between the performance of male and female observers ($p = 0.6$) (Fig. 7).

The age ranges given varied immensely, (smallest = 1 h wide, largest = 360 h wide), indicating considerable variability in the confidence of the observers. Although many of the ranges given were very large, only 39.4% actually contained the true bruise age.

4.2. Task 2

In the majority of cases, the bruise images were placed in chronological order with relatively few or no errors at all (82% made two errors or less). However, performance was still very variable and appeared to depend on which bruise was viewed (Fig. 8).

In clinical practice, accuracy requirements would clearly depend on the scenario. However, it would be reasonable to require accuracy to within 24 h.²⁰ From these results, this limit has been

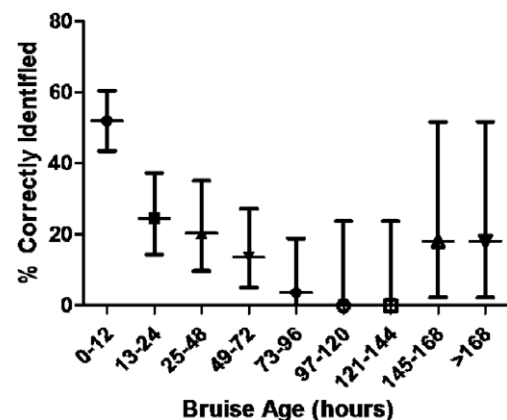


Fig. 5. Graph showing the proportion of bruises in each age range correctly identified, together with the upper and lower limits of the 95% confidence intervals.

exceeded repeatedly, with only 48% being estimated to within 24 h of the true age.

5. Discussion

The greatest accuracy being achieved in the youngest age group, is perhaps due to the visible erythema in the images, or the fact that it was very difficult to edit out completely all traces of the syringe imprint on the skin. Erythema can disappear very quickly and this could explain the rapid decline in accuracy and precision only a few hours after bruise infliction. This suggests that the use of

Table 2

Table showing the number of bruises in each age category that were allocated to each age category by the observers.

		Estimated age (h)								Total
		0–12	12–24	25–48	49–72	73–96	97–120	121–144	145–168	
True age (h)	0–12	74	26	10	11	8	2	2	2	142
	12–24	15	15	11	5	5	3	1	0	61
	25–48	2	8	9	10	5	1	2	1	44
	49–72	5	10	6	6	5	3	2	2	44
	73–96	3	8	3	3	1	2	1	3	27
	97–120	1	4	0	3	1	0	0	0	11
	121–144	0	6	1	2	3	5	0	2	24
	145–168	3	0	2	0	2	1	0	2	11
	>168	1	4	1	2	0	1	0	2	11

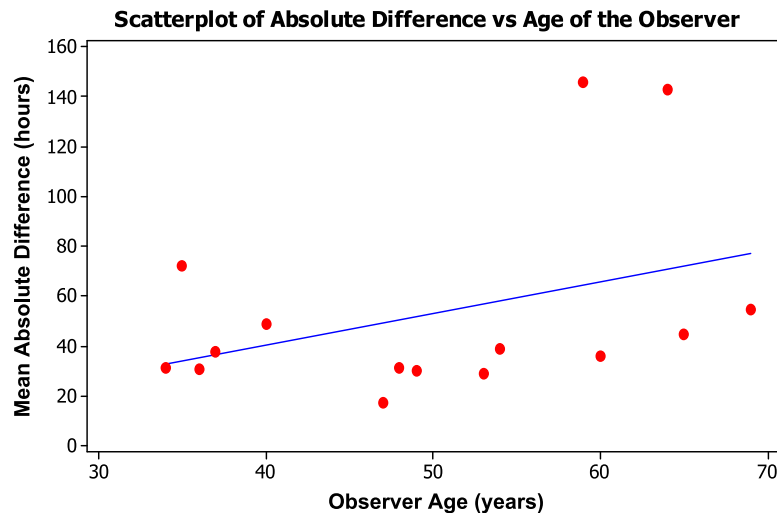


Fig. 6. Scatterplot of absolute difference vs. age of the observer.

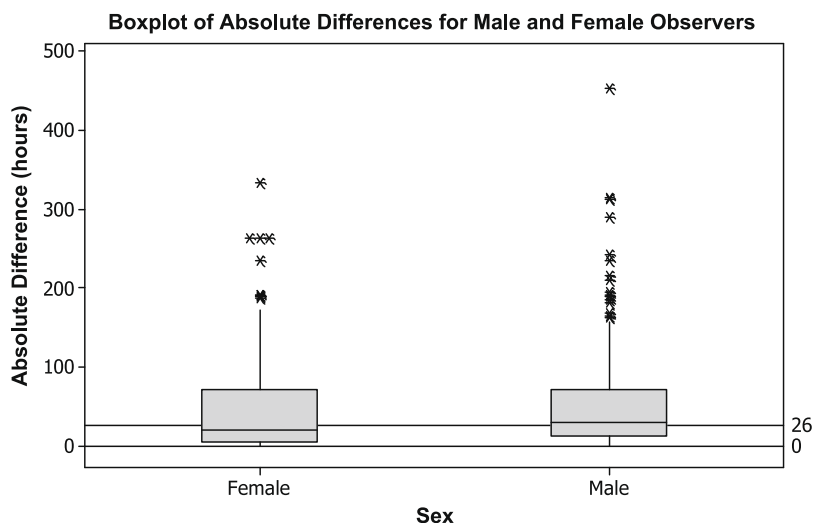


Fig. 7. Boxplot of absolute differences for male and female observers.

associated features such as swelling, erythema and tenderness may help significantly in ageing a very fresh (0–12 h) bruise.

A previous study, which assessed the ability of experienced emergency paediatricians to age bruises, by direct examination, found that accuracy for ageing bruises <48 h old was 77.3% (95% C.I. 54.6–92.2%).²⁰ In this study, accuracy for 0–48 h bruises was 39.7% (95% C.I. 33.5–46.1%), suggesting that dating bruises from photographs is less accurate than direct examination. Possible reasons for this include: unreliable colour reproduction, loss of contours, it is not possible to palpate the injury for tenderness, nor to obtain a history directly from the patient.

In this study, there was no significant difference between male and female observers ($p = 0.553$). However, the prevalence of colour blindness in the male population is 8 in 100,²¹ therefore, it may be that in a larger population of observers a difference would be seen.

In Task 2, accuracy seemed to depend on the bruise itself, rather than on the observer. This is perhaps because some bruises had clearer changes in size and intensity than others. Clinically it is important for experts to be able to identify whether one bruise is older than another in scenarios such as 'the battered child.'

5.1. Advantages of the techniques used in this study

By using bruises that were self-inflicted in the laboratory it was possible to know exactly the true age of the bruise. Previous studies have used patients presenting to hospital with bruising and relied on patient histories to ascertain the age.^{18,20} It was also possible to control the force with which the bruise was inflicted and produce a set of 'standard' bruises. Moreover, it enabled the photographs to be taken under controlled conditions with consistent ambient lighting.

The use of digital photography enabled the images to be subjected to colour analysis prior to printing. Using Photoshop software it was possible to digitally edit the images so that in aspects other than the bruise they were identical, thus producing a standard set of bruise images.

5.2. Limitations and potential sources of error

5.2.1. Limitations in the appearance of the bruises

Only 1 observation estimated that a bruise was 0 h old. All other observations assumed that at least some time had elapsed. This is

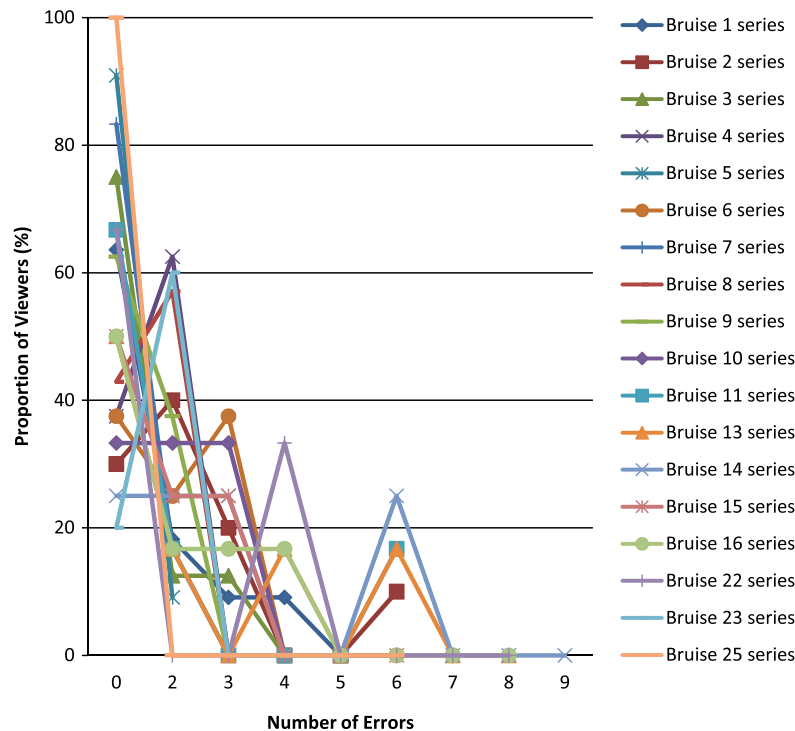


Fig. 8. Graph showing the proportion of observers who made 0, 2, 3, 4, 5, 6, 7, 8 and 9 errors for each series of bruise images placed in chronological order.

perhaps because an artificial method of inflicting bruises was used that produced immediate bruising, whereas, in 'real-life' bruises often take some time to develop.

All bruises were inflicted on Caucasian subjects and so this study is not able to elicit the accuracy of forensic experts in ageing bruises in the general population. Moreover, all bruises were inflicted at the same site, and since appearance and development may vary with the anatomical position, this study cannot elicit the accuracy for all bruises. Nevertheless, given that as many variables as possible were excluded, the results of this study probably represent the best accuracy that can be achieved from photographs.

5.3. Limitations of the photographs

Colour reproduction in photographs is unreliable and since the ageing of a bruise is achieved primarily on the basis of colour this may have affected the results. Unfortunately, it was not possible to standardise the colour conditions of the images, using the software available.

All bruises were imaged at Time 0. However, due to variability in the length of time the bruises took to resolve and also in the availability of the subjects for imaging, not all bruises had the same number of photographs taken at the same time intervals. This meant that the images were biased towards young bruises and therefore, the observers viewed a greater proportion of young bruises than old. Since each expert only saw one image of each bruise, the images of bruises that were photographed more frequently were seen by fewer observers than those of which there were only a few images.

6. Further work

This study was intended to assess the practicalities of producing experimental bruises and to determine the accuracy with which forensic experts can estimate the age of a bruise from a photograph.

Several areas for further research have been highlighted:

- To investigate alternative methods of producing 'artificial' bruises that are more realistic e.g. using a weighted pendulum or dropping a ball-bearing down a tube onto the selected bruise site.
- To determine whether experts can place different bruises both in the same and in different anatomical locations in chronological order (a more authentic scenario).
- To compare the ability of forensic experts to age bruises from photographs with bruise dating by direct examination of the injury.

7. Conclusions

Since accuracy depended greatly on the age of the bruise, little extrapolations from the values for differences between the estimated ages and the real ages can be made beyond the bruises involved in this study. Categorical analysis of this data is perhaps more useful, which showed that accuracy was greatest for very fresh bruises (0–12 h); however, extreme misjudgements still occurred in this age group. Performance between observers is very variable, but appears to be unaffected by sex and age of the observer. The confidence of the observers was also very variable.

Placing bruise images in chronological order appears to be an easier task. Even so, performance was still very variable and seems to depend on the bruise.

Based on the results of this study, forensic experts' estimates of bruise age from photographs are, at best, unreliable. However, it appears that the vast majority of observers are better able to place bruises from the same subjects in their chronological order.

Conflicts of Interest

None declared.

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Ethical Approval

The study was submitted to the local ethics committee for consideration and it was agreed that ethical approval was unnecessary.

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